

PATENT

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METHOD AND APPARATUS FOR MONITORING SATURATION LEVELS OF
10 SOLVENTS USED DURING RAPID PROTOTYPING PROCESSES

Background of the Invention

(1) Field of the Invention

15 This invention pertains to the field of monitoring
saturation levels of dissolved solutes in solvent
solutions. More particularly, this invention pertains to
the use of electrical characteristics of such solutions to
determine and monitor saturation levels.

20 (2) Background

During some rapid prototyping processes, such as
stereolithography, it is common to perform a step removing
uncured and partially-cured residual resin from formed

objects using a solvent such as Tripropylene Glycol Methyl Ether, which is also referred to as Glycol Ether TPM, or just TPM. This step is typically performed to remove uncured resin that coats an object after the object has
5 been formed and to remove undesired partially-cured resin therefrom, prior to performing an additional step of "baking" the part with ultraviolet light to fully cure all resin remaining in the part.

Typically, the step of removing resin from objects
10 comprises submersing the formed objects in a bath of solvent for a period of time. During this step, an agitator is often provided in the bath of solvent to create relative movement between the objects and the solvent.

As the bath of solvent is utilized to remove resin
15 from objects, the concentration level of dissolved resin in the solvent bath increases. Eventually, the solvent becomes fully saturated with dissolved resin, and thereby becomes ineffective in removing further resin from objects. Once it is determined that solvent has become saturated,
20 the bath of solvent is typically fully or partially drained, and then resupplied with fresh solvent.

Determining when a bath of solvent has become

saturated or predicting how soon such a bath of solvent will become saturated has been difficult. Resort is often made to empirical data as a guide for determining when to service a bath solvent. However, such data is often
5 inaccurate or unreliable and, as a result, solvent is often stocked in reserve. Additionally, the unpredictable timing of the solvent's saturation results in unexpected service delays that increase production periods and disrupt schedules associated with the production of resin cured
10 objects.

Summary of the Invention

The present invention eliminates many of the difficulties associated with prior art techniques of
15 determining when a bath of solvent has become saturated or predicting how soon such a bath of solvent will become saturated. In general, the invention allows for the constant monitoring of the saturation level of resin in solvent baths.

20 In one aspect of the invention, a method comprises forming at least a portion of an object by curing resin. This method further comprises the step of providing a

storage device containing a liquid. The liquid comprises a solution of solvent and dissolved resin, such that the solution has a ratio of the dissolved resin to solvent.

Additionally, the method comprises the step removing an

5 amount of resin from the object via the liquid in a manner such that the amount of resin becomes dissolved in the liquid and thereby increases the ratio of the dissolved resin to the solvent of the liquid. The increase of the ratio alters an electrical characteristic of the liquid.

10 The method yet further comprises the step of utilizing changes in the electrical characteristic of the liquid as an indicator of the ratio of the dissolved resin to the solvent of the liquid.

In another aspect of the invention, a method comprises
15 forming at least a portion of an object by curing resin.

This method also comprises the step of providing a storage device containing a liquid. The liquid comprises solvent and dissolved resin, and has at least one electrical characteristic. Additionally, the method comprises

20 removing an amount of resin from the object via the liquid in a manner such that the amount of resin becomes dissolved in the liquid and thereby alters the electrical

characteristic of the liquid. Furthermore, the method comprises removing an amount of the liquid from the storage device and adding solvent to the liquid in the storage device in response to a measurement of the electrical characteristic of the liquid. The solvent added to the liquid in the storage device thereby alters the electrical characteristic of the liquid in the storage device.

In yet another aspect of the invention, a method comprises the step of providing a storage device containing a liquid. The liquid comprises solvent and solute and has a ratio of the solute to the solvent. This method also includes removing an amount of material from an object via the liquid in a manner such that the amount of material becomes additional solute in the liquid and thereby increases the ratio of the solute to the solvent of the liquid. The increase of the ratio alters an electrical characteristic of the liquid. Additionally, the method comprises the step of utilizing changes in the electrical characteristic of the liquid as an indicator of the ratio of the solute to the solvent of the liquid.

In yet another aspect of the invention, an assembly comprises a storage device, an amount of liquid stored in

the storage device, and a monitoring device. The liquid comprises solvent and dissolved resin. The monitoring device is in communication with the liquid in the storage device and is adapted and configured to pass an electric
5 current through at least some of the liquid and to produce a plurality of signals indicative of a plurality of conditions of conductivity of the liquid in the storage device.

While the principal advantages and features of the
10 invention have been described above, a more complete and thorough understanding of the invention may be obtained by referring to the drawings and the detailed description of the preferred embodiment, which follow.

15 Brief Description of the Drawings

Figure 1 is a perspective view showing a cleaning apparatus having a liquid storage device for removing resin from objects and a monitoring device for practicing the invention.

Figure 2 is a schematic of the electrical circuitry of the
20 preferred embodiment of a monitoring device for practicing the invention.

Figure 3 is a flowchart of the preferred method of practicing the invention.

Reference characters in the written specification indicate corresponding items shown throughout the drawing figures.

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Detailed Description of the Preferred Embodiment of the Invention

In general, the present invention involves the monitoring of at least one electrical characteristic of a solvent used to dissolve and remove undesirable resin from objects. A preferred embodiment of a cleaning apparatus for practicing the invention is shown in Figure 1. This cleaning apparatus, generally indicated by reference numeral 20, is particularly adapted for the removal of resin from prototype objects during a process of forming such objects via a stereolithography process. The cleaning apparatus 20 generally comprises a liquid storage device 22 containing a bath of solvent 24, and a monitoring device 26.

20 The liquid storage device 22 is preferably a commonly available standard liquid storage device of the type typically utilized in connection with most

stereolithography techniques. As shown, the storage device 22 has an internal cavity 28 that is open to the environment above the storage device such that objects can be easily inserted into and removed from the cavity. A
5 removable or openable lid or the like (not shown) could also be utilized to selectively close the cavity of the storage device 22 so as to limit evaporation of solvent from the bath of solvent 24. Like most liquid storage devices used for similar purposes, the storage device 22
10 preferably comprises an agitation device (not shown) which supports the stereolithography objects when such objects are submerged in the bath of solvent 24. The agitation device is also preferably adapted and configured to raise and lower parts into and out of the bath of solvent 24 and
15 to create agitation sufficient to cause relative movement between the solvent and the objects submersed therein. The bath of solvent 24 preferably comprises TPM and, assuming the bath has been already been utilized to remove resin, some amount of dissolved resin.

20 The monitoring device 26 is preferably configured to be supported by the liquid storage device 22 in a manner such that a portion of the monitoring can be seen from the

workplace surrounding the storage device. Another portion of the monitoring device 26 is preferably positioned in a manner such that it is submerged in the bath of solvent 24.

The monitoring device preferably comprises the
5 electrical circuit 30 shown in Figure 2. The electrical circuit 30 comprises an electrical power source 32, at least one pair of spaced probes 34, a plurality of light-emitting diodes 36, and a plurality of variable resistors 38. The electrical power source 32 is preferably a
10 rechargeable or replaceable battery, but could also be another type of power source such as the power supply of the liquid storage device 22 or any electrical outlet. Each pair of spaced probes 34 is preferably positioned such that it is submerged in the bath of solvent with its probes
15 spaced approximately between $3/4$ and $7/8$ inches apart from each other. Preferably, each one of the variable resistors 38 is connected in series with one of the light-emitting diodes 36 and with one of the pairs of spaced probes 34. Each of such series is also preferably connected in
20 parallel with the power source 32.

In use, the bath of solvent 24 in the liquid storage device 22 of the cleaning apparatus 20 initially has a

ratio of dissolved resin-to-solvent (resin-to-solvent concentration ratio) that is at or near zero. An object at least partially formed of resin is then placed into the bath of solvent 24 for purposes of removing partially cured and uncured resin therefrom. Figure 1 depicts such an object 40 submersed in the bath 24.

With the object 40 submersed in the bath 24, the agitation device creates relative movement between the object 40 and the bath 24 and effectively mixes the bath. Throughout this procedure, the solvent in the bath 24 dissolves and removes some of the resin from the object 40, thereby increasing the resin-to-solvent concentration ratio of the bath. After a desired amount of resin has been removed from the object 40, the object is removed from the liquid storage device 22 of the cleaning apparatus 20 for further processing. It should be appreciated that, typically, many objects can be washed in the liquid storage device 22, individually or in batches, before the solvent becomes saturated, and that as more and more objects are washed in this manner, the resin-to-solvent concentration ratio of the bath 24 increases. Thus, after a sufficient amount of resin has been dissolved in the solvent, the

resin-to-solvent concentration ratio of the bath 24 approaches saturation such that the bath can no longer effectively remove resin from objects.

The monitoring device 26 monitors the resin-to-solvent
5 concentration in a manner eliminating the guesswork of determining how close the bath 24 is to needing to be replaced with fresh solvent. To this end, the bath of solvent 24 in which the spaced probes 34 of the monitoring device 26 are submerged creates an electrical pathway
10 between each pair of probes. Each of these pathways has an impedance that is dependent upon the spacing between the respective pair of spaced probes 34, and upon the conductivity of the resin and solvent solution in the bath of solvent 24. The spacing between the probes 34
15 preferably remains constant. However, the conductivity of the resin and solvent solution in the bath of solvent 24 varies depending upon the resin-to-solvent concentration. In particular, experiments conducted by the inventor generally indicate that the conductivity of the liquid in
20 the solvent bath increases as the resin-to-solvent concentration increases. Thus, as the resin-to-solvent concentration of the bath of solvent 24 increases, the

impedance of the electrical pathway between each pair of the spaced probes 34 of the monitoring device 26 decreases. As the impedance between a given pair of the spaced probes 34 decreases, the total resistance of the electrical pathway formed by the pair of probes and its respective resistor 38 and LED 36 decreases. Thus, it should be appreciated that when the impedance across each pair of probes 34 drops below a particular value, the voltage across the LED 38 that is connected in series therewith will increase to a point sufficient to illuminate the LED. Moreover, each of the LEDs 36 can be independently configured to illuminate when the impedance of the solution drops below a particular set-point by adjusting the resistance of its respective variable resistor 38.

A flowchart of the preferred operation of the cleaning apparatus in connection with the monitoring device is shown in Figure 3. As resin is removed from objects placed in the liquid storage device, the monitoring device continuously monitors the bath of solvent as described above. Preferably, the variable resistor that is connected in series with a first one of the LEDs is adjusted so that this first LED illuminates even when the solvent bath

contains no resin. In other words, the first LED illuminates under all impedance conditions of the bath of solvent. This is done so as to verify to the person using the cleaning apparatus that the monitoring device is
5 functioning. Additionally, the variable resistor that is connected in series with a second one of the LEDs is preferably adjusted such that the second LED illuminates when the resin-to-solvent concentration is above particular value determined to be when the bath of solvent is reaching
10 the end of its usefulness, but prior to when the bath of solvent is needed to be replaced. Furthermore, the variable resistor that is connected in series to yet a third one of the LEDs is preferably adjusted such that this third LED will illuminate only when the impedance of the
15 bath of solvent drops below a value indicative of the need to replace the bath of solvent with fresh solvent. If so desired, additional LEDs can be configured to illuminate when the impedance of the bath of solvent drops below any other impedance set-point. These set-points are preferably
20 determined by trail and error, or by adjusting a resistor to illuminate an LED when the bath of solvent is known to be at the relevant resin-to-solvent concentration level.

In view of the foregoing, it should be appreciated that, as the resin-to-solvent concentration increases, the number of illuminated LED's increases. Thus, an operator using the cleaning apparatus is continually informed of the
5 condition of the bath of solvent. Moreover, the illumination of an LED, such the second LED described above, can serve the purpose of notifying an operator of the cleaning apparatus that the bath of solvent, while still being effective in removing resin, will soon need
10 replacing. Thus, upon the illumination of such an LED, the operator can take steps to ensure that a sufficient stock of solvent will be on hand when the bath of solvent reaches the end of its useful life. The illumination of yet other LEDs can serve as an indication that the resin-to-solvent
15 concentration is sufficiently high to warrant increasing the cleaning time of objects. Hence, practicing the present invention allows for, among other things, more efficient scheduling of solution changes, more efficient stocking of solvent, and more efficient overall
20 productivity of the cleaning apparatus.

While the present invention has been described in reference to a specific embodiment, in light of the foregoing, it should

be understood that all matter contained in the above description or shown in the accompanying drawings is intended to be interpreted as illustrative and not in a limiting sense and that various modifications and variations of the invention may be constructed without departing from the scope of the invention defined by the following claims. For example, it should be appreciated that monitoring devices could be configured to only periodically monitor the bath of solvent or to do so only upon a request signal initiated by the operator. Furthermore, in lieu of LEDs, monitoring devices could be configured to use acoustic signals, text messages, or any other method of conveying the status of the bath of solvent. Additionally, the circuitry of the monitoring device need not necessarily be similar to the monitoring device of the preferred embodiment. For example, a monitoring device could have fewer components, such as only a single pair of space probes, or could have additional components, such as Zener diodes to protect the LEDs. Still further, although the invention is described as being used in connection with stereolithography, it should be appreciated that it could also being utilized in connection with other rapid prototyping processes or with any process utilizing solvents.

Thus, other possible variations and modifications should be appreciated.

Furthermore, it should be understood that when introducing elements of the present invention in the claims or in the above
5 description of the preferred embodiment of the invention, the terms "comprising," "including," and "having" are intended to be open-ended and mean that there may be additional elements other than the listed elements. Similarly, the term "portion" should be construed as meaning some or all of the item or element that
10 it qualifies.